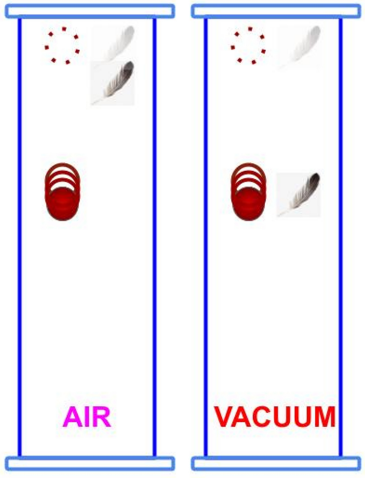
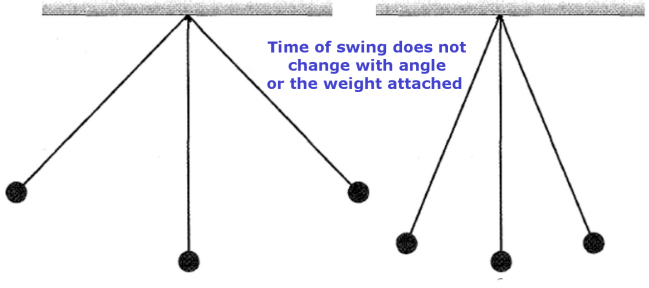
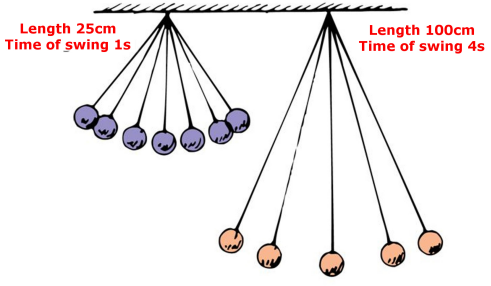
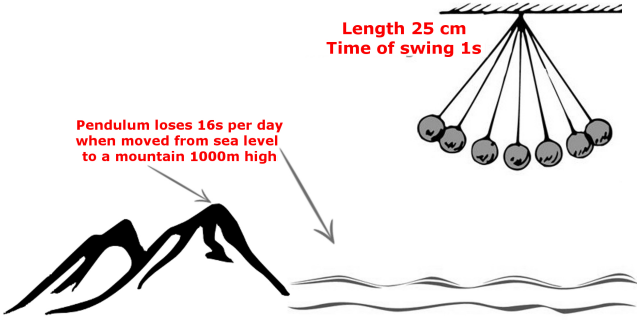


Anything dropped from a height falls towards the ground because of the force of gravity. Galileo, the Italian scientist is said to have dropped spheres from the top of the leaning tower of Pisa to show that the speed with which they travel and the time taken to reach the ground does not depend on the weight of the sphere. In recent years, an iron ball and a feather were photographed falling together from a height in a room only if all the air has been pumped out. {Picture left} This is another example of the intimate link between mathematics and physics.

Since ancient times, masons and builders have used a plumbline to check that the walls they are building are vertical. A plumbline is a pointed weight hanging at the end of a piece of string. This is a very useful tool to understand the force of gravity. A pendulum as the plumbline is called in the physics laboratory can be easily set to move to and fro in a single plane. The time taken for the pendulum to go from the left extreme position to the right extreme position and return is called the time period of the pendulum. The time period does not depend {Picture left} on the weight attached to the pendulum or how far the pendulum is swinging. This is why

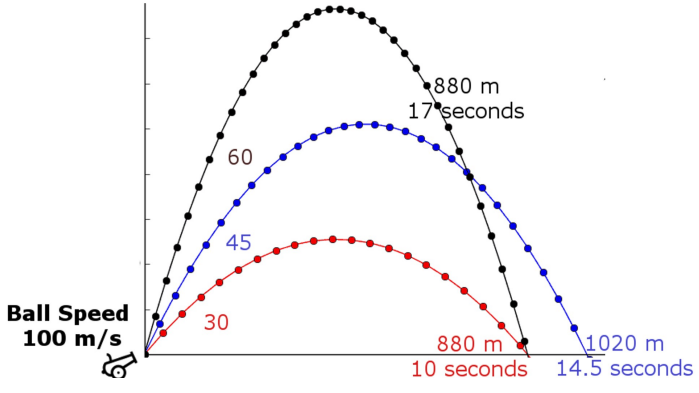




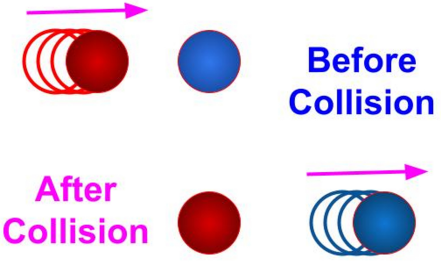


clocks made in the eighteenth century used pendulums. The time period of the pendulum will change in a simple way with its length. At sea level, a pendulum 25 cm long will have a time period of 1s (second). If the length is increased to one meter, four times longer, the period will also increase to 4 s.{Picture left above} If the 25 cm long pendulum is taken from the sea level to a height of 1000m, the period will decrease slightly and the pendulum will lose 16 seconds in a day. {Picture right above} Students in high schools perform such experiments and compare their results with the time period calculated using Newton's law.

Cannons and catapults have been used in wars for many centuries. It was always known that to increase the distance travelled by the cannon ball, the cannon should not be held horizontal but at a small angle. Using the law of gravitation, it can be shown that the range, the distance travelled by the cannon ball is largest when the angle is 45° from the horizontal. {Picture top, opposite page} It is also easy to calculate how the range changes with the angle. Such examples show the importance of Newton's laws of motion and gravitation.



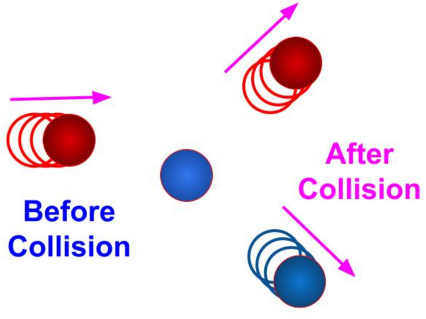
A force is required to change the speed or direction of a moving object. The main force acting on a planet, a pendulum or a cannon ball is the force of gravity. Under some conditions friction is another force. In a game of snooker or billiards, one ball, the striker is used to hit other balls on the table. If skilfully hit, the striker will come to a complete halt while the second ball will move in the same direction and with the same speed. {Picture below} But if the same experiment is repeated with the second ball which is half as heavy as the first, when the first ball stops, the second moves with twice the speed. Once the player has set the first ball in motion, there is no other force acting on the balls. Because of friction with the table surface, the balls will slow down and stop. If we imagine that there is no friction one can easily see that the product of the mass and speed called the momentum does not change when the two balls collide. In physics the name mass is used rather than the more common word weight. That is why when the mass of the ball is reduced to half, the speed has doubled. Force changes the momentum. When the mass does not change, the change in speed or direction indicates that a force is present. To measure the force, we need to consider not just the change in momentum



but how fast that change has taken place. In physics, acceleration is the rate at which speed is changing in a given direction. If the same force were acting and the mass of the body was decreased by half, the acceleration would double. The force is thus the product of the mass and acceleration. If the force and mass both increase by the same amount, the acceleration would not change. This happens with bodies on the surface of the earth. The force of gravity between the earth and the various bodies falling toward the earth is not the same. If the mass of the body is doubled the force of gravity is also doubled. So, though the force of gravity on all the bodies falling towards the earth is not the same, the acceleration is the same. When a body is taken from the sea level to the top of a mountain, the acceleration on all bodies changes by the same amount. This explains why the ball and feather fall together and why pendulum time period changes as mentioned above.

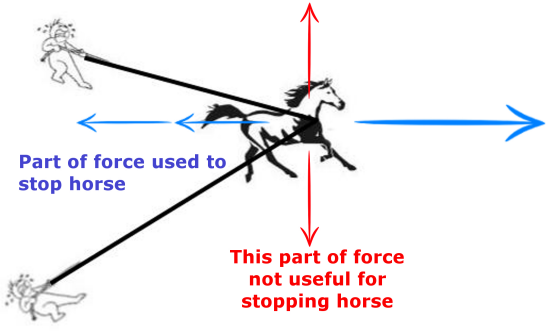
Newton's definition of the force as the product of mass and acceleration and his mathematical formula for the universal law of gravitation are the foundation stones of physics. That momentum will not change in the absence of an external force is part of this mathematics. This is the reason scientists give this a special status and call it **"the principle of conservation of momentum"**. This has been experimentally verified in countless experiments starting with the simple collisions described above. More importantly, because conservation of momentum is part of mathematical laws of physics, scientists refuse to consider that the law of conservation of momentum can be wrong and reject any experimental result that claims to contradict it.

When one ball collides with another at an angle, both of them move in different directions. Even this collision obeys the law of conservation of momentum. But we have to determine the momentum in each direction separately. To understand this, consider that the first ball



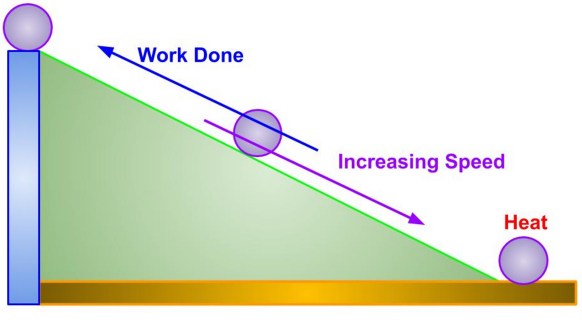
was moving due east before collision and north-east after the collision. {Picture left} The second ball was stationary before collision and moving south east after the collision. First you have to divide the speed of the first ball along the north east into two parts, its speed due east and its speed due north. Similarly the speed of the second ball in the south east direction is divided into two parts, one due east and the other due south. Multiply the speed components with the masses of the two balls. Now you will notice that the sum of the momentum of the first ball due east after collision and of the second ball due east after the collision equals the momentum of the first ball before the collision. Before the collision the second ball had zero momentum. It was stationary. Similarly, the momentum of the first ball due north after collision will be equal to the momentum of the second ball due south after the collision. They are equal and opposite. Their sum is zero. Neither of the two balls had any momentum in the north south directions before collision. All this elaborate mathematical calculation is necessary to confirm that the law of conservation of momentum is still obeyed. This is a good example of how mathematics and physics are related. This example also shows that for understanding physics, the direction of speed and momentum are necessary.

One important question. Is the use of mathematics to divide the speed of the ball in the north east direction into parts along the north and east directions justified? This is not merely justified, it is absolutely necessary to understand the relationship between force and energy and the importance of the law of conservation of energy. As an example, consider



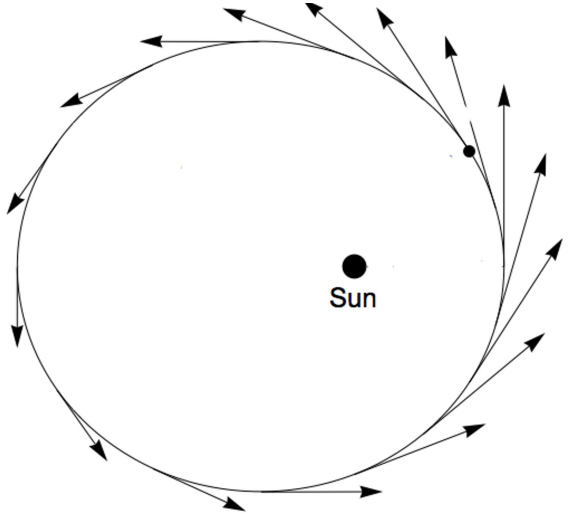
that two humans are trying to stop a runaway horse using two ropes. Each individual is applying a force in the direction of the rope. When the horse stops, the force applied by the individuals must be equal to the force exerted by the horse and in a direction opposite to the one in which the horse is running. {Picture left} Only then will the two forces cancel. So a part of the force along the ropes is acting in that direction. As the angle between the two humans increases, it becomes more difficult to stop the horse. The part of the force in the direction opposite to the moving horse decreases. When the two individuals are exactly opposite to each other the horse will pull them along. The force on the ropes will not be used for stopping the horse but for a tug of war between the individuals. Just as the parts of momentum in different directions were determined earlier, parts of force or acceleration in different directions can be calculated.

The product of the value of the force and the distance moved by the object in the direction or opposite to the force is called energy or work done in physics. Words like force, work and energy have specific meanings in physics. It is a common experience that one has to do work to lift an object from the ground level. The work is done because the object is moving against the



force of gravity. {Picture bottom right opposite page} Whether we lift the object vertically or pull it up along an inclined plane, the distance moved against the force of gravity is the same. It is the height from the ground. So the energy required is the same. But along the inclined plane the distance moved is more. So a smaller force is sufficient. The work done or energy is the product of a smaller force and larger distance. This work done is available with the body and is called potential energy. As the body returns to the ground sliding down the inclined plane, the potential energy is converted into what is called the kinetic energy. When the body hits the ground and stops, the kinetic energy is converted into heat, Energy is never “lost” it is converted into other forms. This is **"the law of conservation of energy"**.

Planets moving in orbits without any change is a proof of the law of conservation of energy. As the planets move in an elliptical orbit, their speed and direction change from minute to minute. {Picture right} The arrows in the picture show the changing direction. The length of the arrow is proportional to the speed. The planet has higher kinetic energy when it is moving faster. From time to time, as the speed increases and then decreases, the potential energy is converted into kinetic energy and back into potential energy again. If the smallest amount of energy were lost, over millions of years, the planets would have moved closer to the sun and finally fallen into it.



Just like the law of conservation of momentum, the law of conservation of energy has been verified by countless experiments. Both of them are part of the mathematics used in physics. That is the real strength. No one has ever developed a mathematical theory of physics that does not include these laws of conservation. Because of the mathematical relations, the countless experiments mentioned above strengthen each other. That is the reason modern scientists will immediately dismiss any claims that violate these laws. We can only see a hero hit by a bullet crashing through a glass window in movies. It violates the law of conservation of momentum. However fast the bullet may travel, its momentum is too small for human to crash through glass.